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Measurements of upper tropospheric and stratospheric water vapour content over Delhi, using ground based solar infrared spectroradiometer

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Abstract : Infrared absorption spectra recorded at National Physical Laboratory, New Delhi in January, May, June and July, 1992, using Solar Infrared Spectroradiometer and radiosonde data obtained for the same period at the same station, have been analysed to determine the upper tropospheric and stratospheric water vapour content. The solar infrared spectroradiometer measures total atmospheric water vapour content radiosonde measures water vapour upto lower troposphere. From the comparison, upper tropospheric and stratospheric water vapour content is calculated.

Keywords : Troposphere, stratosphere, water vapour, infrared absorption spectra

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1. Introduction

Water vapour is one of the most important trace gases in the earth's atmosphere system. It plays an important role in the balance of radiations and in the photo-chemistry of the lower and upper atmosphere. Information on the temporal and spatial variability of water vapour is useful in understanding dynamic as well as chemical atmospheric processes. The aim is the evaluation of the upper tropospheric and stratospheric water vapour content with good accuracy, and to study the seasonal variation of water vapour (peak winter and peak summer months).

Infrared (IR) absorption spectroscopy has proved to be one of the most powerful methods for studying the water vapour in the earth's atmosphere. Studies of this nature are

made in the past from the surface, from low flying aircrafts, balloons and satellites by a number of workers [1–9].

The adopted method follows the idea firstly suggested by Fowle [10] of measuring the total atmospheric water vapour content using the features of the near-IR solar spectrum, and successfully used by Tomasi and Guzzi [11], Martin *et al* [12], Borghesi *et al* [13] and Ghosh *et al* [14] in the recent past.

This paper presents the results of a quantitative analysis of absorption by water vapour solar absorption spectra recorded at a number of zenith angles in January, May, June and July, 1992 at National Physical Laboratory, New Delhi (28.7° N and 77.2° E). The spectral data were recorded with a solar infrared spectroradiometer with a scan time of 30 seconds. The solar infrared spectroradiometer measures irradiances in the two wavelengths 6.5 μm and 6.499 μm. The first wavelength is the absorption line of water vapour and second is a line where there is negligible absorption of water vapour (atmospheric window region for water

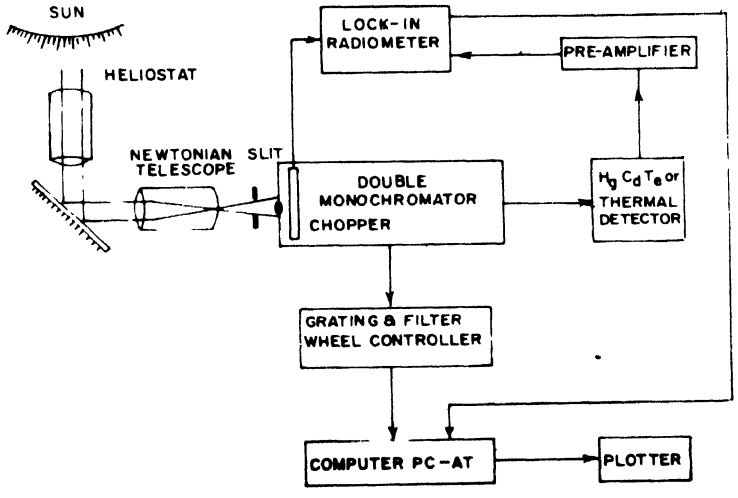

Figure 1. Solar Infrared Spectroradiometer.

vapour). Taking into consideration the radiative extinction due to Rayleigh molecular scattering, the aerosol operated scattering and the strong absorption due to water vapour, an inversion technique is developed to retrieve atmospheric water vapour content. The water vapour content in the lower troposphere is calculated using radiosonde measurements for the same period taken at same station. By comparison of atmospheric water vapour content obtained from solar infrared spectroradiometer and water vapour content in the lower troposphere from radiosonde measurements, the upper tropospheric and stratospheric water vapour content is deduced.

2. Experimental arrangements

A block diagram of the experimental apparatus, controlled by a Sun tracker, is shown in Figure 1.

The Solar Infrared Spectroradiometer consists of double monochromators through which the solar radiations fall on HgCdTe detector which has a spectral response between 1 to 15 μm. While tracking the Sun, the infrared spectroradiometer measures the transmitted solar intensity in wavelength interval of 0.001 μm to retrieve water vapour using spectral lines of 6.5 μm and 6.499 μm. The centre of water vapour absorption band falls at 6.5 μm, and 6.499 μm is taken as reference atmospheric window. The overall spectral region from 1 μm to 15 μm is divided into smaller overlapping wavelength intervals using optical grating, which reduces the sampling rate, maximizes detected energy and improves the signal-to-noise ratio of spectra. The signal-to-noise ratio of the instrument is about 1000. The infrared spectroradiometer is controlled by a computer which accommodates a large dynamic range of data values, displays and plots the measured absorption spectra and stores the data on floppy diskettes.

3. Data analysis

The data reduction technique developed for analysis of high resolution spectra and employed for retrieval of atmospheric water vapour content from infrared observations, has been discussed in a previous publication [14]. This technique determines the water vapour content (g cm^{-2}) taking into account the contribution of Rayleigh molecular scattering, the scattering due to the presence of aerosol in the atmosphere and the absorption from the various gases present in the atmosphere. The physical parameters needed to calculate atmospheric water vapour content are the intensity of solar radiation at water vapour absorption line (λ_1 = 6.5 μm), intensity of solar radiation in atmospheric window region for water vapour (λ_2 = 6.499 μm), the line strength and Lorentz half width. The solar intensity at wave lengths λ_1 and λ_2 are calculated from solar infrared spectroradiometer measurements while line strength (S) and Lorentz half width (α) are read from HITRAN tape [15].

The water vapour content (W) can be obtained using formula

$$I_{\lambda_1}/I_{\lambda_2} = \mathrm{Exp}\left[-\sec x\left(K_{w\lambda_1} - K_{w\lambda_2}\right)W\right].$$

The coefficients of water vapour absorption $K_{w\lambda_1}$ and $K_{w\lambda_2}$ are evaluated for Lorentz lineshape from

$$k_{w\lambda_1} = S\alpha\,\lambda_1^2\lambda_2^2/\pi\left[\left(\lambda_1 - \lambda_2\right)^2 + \alpha^2\lambda_1^2\lambda_2^2\right].$$

For finding water vapour content in the lower troposphere by radiosonde, the parameter needed is the absolute humidity or water vapour density. Water vapour density is simply mass of water contained in a unit volume of moist air, expressed in g. m^{-3}. The water vapour density has been found in terms of the partial pressure of the water vapour (e) in mbar, and atmospheric temperature (T) in K. This implies that for each atmospheric temperature at a particular height, corresponding partial pressure of the water vapour has been calculated. Thus, knowing the values of atmospheric temperature and partial pressure of water vapour, the water vapour density can be obtained from the following expression

$$W = 217e/T.$$

The water vapour density so obtained, has been integrated from ground to the maximum altitude of the radiosonde measurements to obtain lower tropospheric water vapour content.

4. Observations and results

The calibration of solar infrared spectroradiometer has been done using a 200 watt quartz halogen tungsten coiled coil filament lamp standard M-655 traceable to NBS spectral irradiance scale with liquid nitrogen cooled HgCdTe detector. This increases the detector sensitivity and radiometric accuracy of the system, since it reduces the infrared background photons and eliminates most of the stray radiations reaching the detector.

For retrieval of water vapour content, the spectral line isolated from overlapping features of other gases are chosen to satisfy the following requirements :

i) the observed intensity for the selected frequency interval and ray paths is not saturated, yet is sufficiently high to provide a good-to-noise ratio.

ii) the weighing functions at the selected frequency are sharply peaked.

iii) the lower energy state is small to minimize the temperature dependence of line strength.

It has proved quite difficult to locate isolated lines with suitable temperature insensitive intensities for analysis. Figure 2 shows the solar spectral irradiance at water vapour absorption

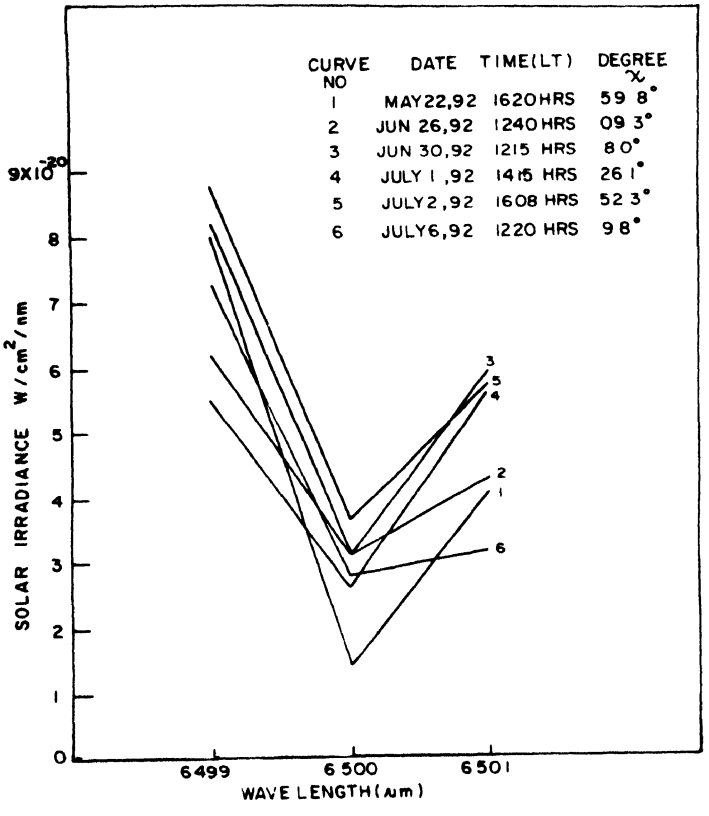

Figure 2. Solar spectral irradiance at water vapour absorption line in the months of May, June and July 1992.

lines 6.499 μm, 6.5 μm and 6.501 μm for the months of May, June, July, 1992 (peak summer months). For comparison, the solar spectral irradiance at same spectral lines for the

month of January, 1992 (peak winter month) are given in Figure 3. The centre of water vapour absorption band falls at $\lambda_1 = 6.5$ μm while 6.499 μm and 6.501 μm are the reference

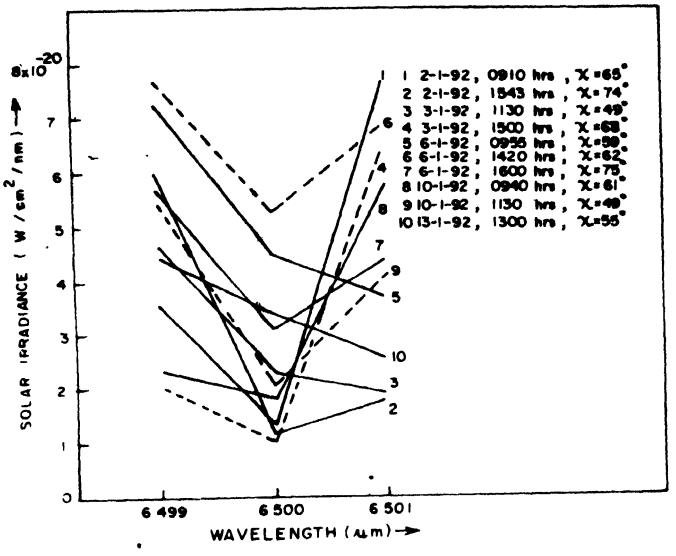

Figure 3. Solar spectral irradiance at water vapour absorption line in the month of January 1992.

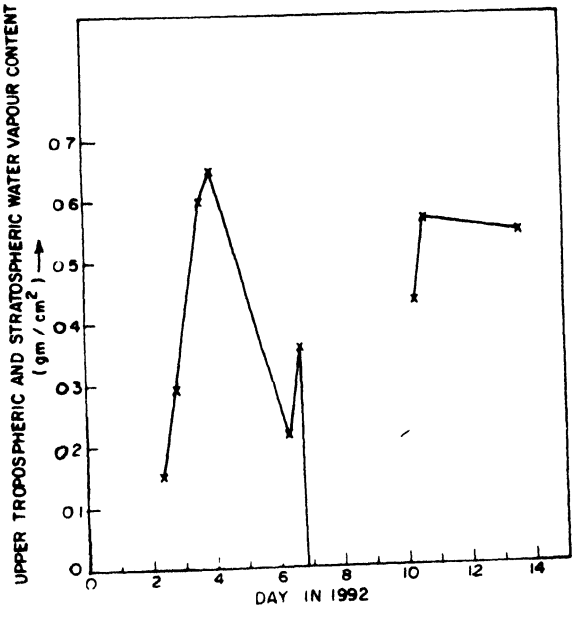

Figure 4. Daily variation of upper tropospheric and stratospheric water vapour content (January 1992).

atmospheric windows for water vapour. At the centre of water vapour absorption band, the absorption is maximum and hence the solar spectral irradiance is minimum, while in the atmospheric window region there is negligible absorption of water vapour. In the present work $\lambda_2 = 6.499$ μm is taken as the reference atmospheric window for water vapour to calculate total atmospheric water vapour content.

In Figure 4, the time-profile of upper tropospheric and stratospheric water vapour content is presented for 2nd, 3rd, 6th, 10th and 13th of January, 1992 between 900 to 1600 hours LT. The upper tropospheric and stratospheric water vapour content is found to vary

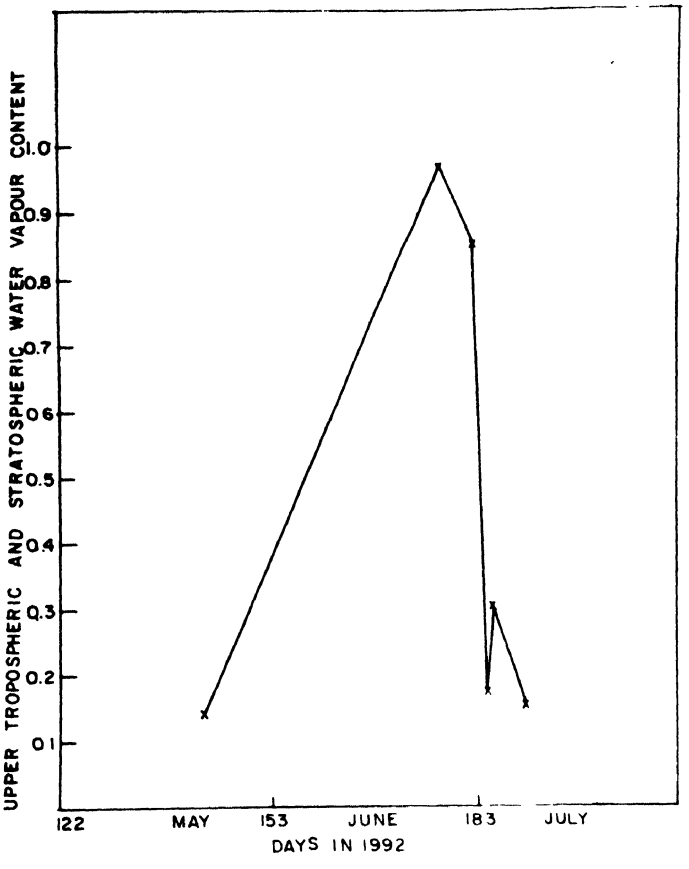

Figure 5. Daily variation of upper tropospheric and stratospheric water vapour content (May, June and July 1992).

between 0.12 to 0.64 g cm^{-2}. Effect of cloud is seen on 6th January at 1600 hours when the infrared spectroradiometer measured the irradiance from the cloud height at about 6 km. Since radiosonde also measures the water vapour content upto height of 6 km (6th January, 1992, 1600 hours) and so measured value of upper tropospheric and stratospheric water vapour content reduces to zero.

In Figure 5, the time profile of upper tropospheric and stratospheric water vapour content is presented for May 22, 1992, June 26, 1992, June 30, 1992, July 1, 1992, July 2,

1992 and July 6, 1992 between 0900 to 1600 hours LT. The upper tropospheric and stratospheric water vapour content is found to vary between 0.14 to 0.97 g cm^{-2}. Effect of clouds is not seen during this period of observations.

It is evident from the above results that water vapour content shows seasonal variations with higher values in summer than in winter.

5. Conclusions

Relevant seasonal fluctuations in the upper tropospheric and stratospheric water vapour content has been observed. The summer months are characterized by rather high maximum values of upper tropospheric and stratospheric water vapour content with mean value 0.43 g cm^{-2}. The maximum value is found to be 0.97 g cm^{-2} in June 1992. In winter month, the mean value of upper tropospheric and stratospheric water vapour content drops to 0.35 g cm^{-2}. The maximum value in January 1992 is found to be 0.64 g cm^{-2}. Effect of clouds on measurements of water vapour content has been observed.

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